Vegetation Distribution on a Gravel Point Bar on the Wilson River, NSW: a Fluvial Disturbance Model

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Vegetation distribution on a gravel point bar on the Wilson River, on the mid-north coast of New South Wales, is determined by the pattern of geomorphic units that comprise the point bar. Morphodynamic interactions between vegetation and fluvial processes vary for these differing geomorphic units, reflecting a combination of successional and hydrogeomorphic processes. Fluvial reworking by floods has created a mosaic of geomorphic units which support vegetation at differing phases of regeneration and growth. Stands of river oak on channel-marginal ridges promote gravel deposition. These features are separated by a series of unvegetated chute channels at the bar head. A range of mid-lower canopy species and more substantive ground cover are evident at the bar core and on the channel-marginal bench, where the dense vegetation cover promotes deposition of fine sands and silts. The bar core is separated from the bench by a scoured flood channel, which supports a lower diversity of vegetation. An extensive, unvegetated bar platform has developed at the apex of the bend. The primary geomorphic unit at the bar tail is an older bar platform unit which has a dense river oak monoculture. This feature has been buried by up to 1 m of sand. Reworking of materials over the point bar surface, and associated implications for vegetation distribution within the riparian zone, are described within a fluvial disturbance model.

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INTRODUCTION

Over the past decade or so there has been growing recognition of the significance of riparian vegetation as a control on river character and behaviour (e.g. Hickin 1984; Thornes 1990; Hupp et al. 1995). As a general rule, streams with thick riparian vegetation cover tend to be narrower than channels with thin streamside vegetation (Andrews 1984; Hey and Thorne 1986). Alternatively, whenever vegetation spreads across the channel zone, it can induce significant instream aggradation (e.g. Burkham 1976; Friedman et al. 1996; Brooks and Brierley, in press).

In an attempt to reduce bank erosion and bed degradation, while improving the ecological and aesthetic value of water courses, vegetation management strategies now form an integral part of many community-based river management plans in eastern Australia (e.g. Raine and Gardiner 1995). The most effective strategies for river rehabilitation *work with* the 'natural' behaviour of river systems. In order to achieve this, underlying controls on the composition and distribution of riparian vegetation must be understood. Based on work performed in the northern hemisphere, two primary models have been used to account for the patterns of vegetation structure within the riparian zone. These are referred to as the successional and hydrogeomorphic models.

Autogenic ecological succession is an orderly, community controlled process that

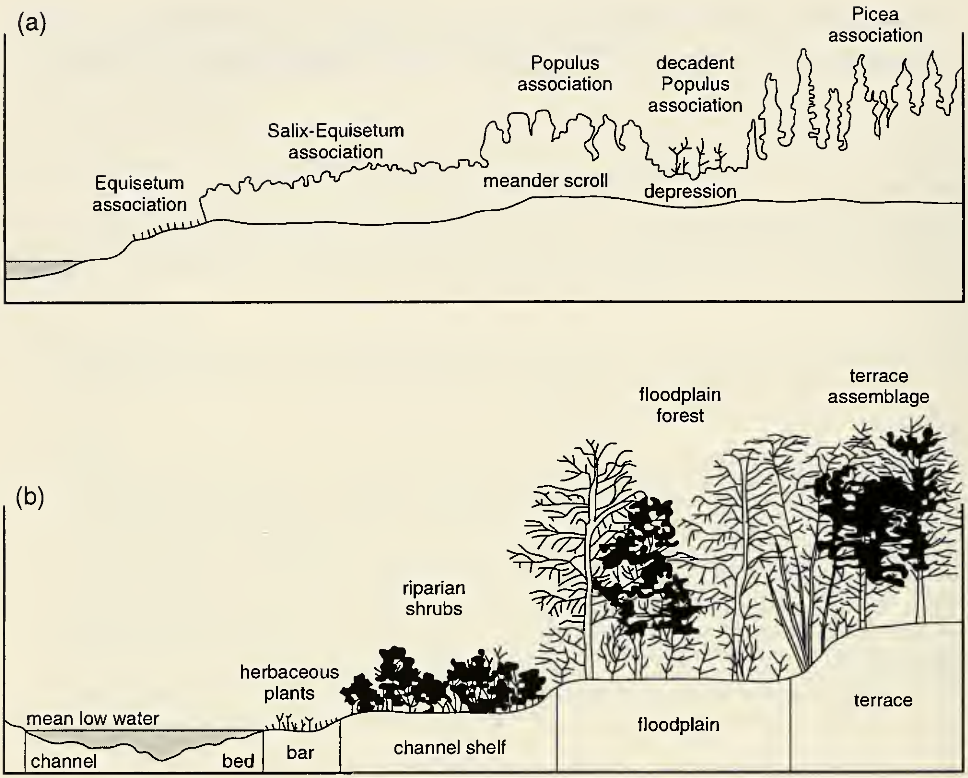

Figure 1. General models of vegetation associations along rivers. (a) The successional model of vegetation distribution across a point bar (explained in the text). The figure shows successional communities and environmental conditions along a dynamic plant succession sequence in the Mackenzie River Delta, Alaska, USA (adapted from Gill 1973). The slip-off slope of the point bar is accreting laterally to the left; (b) the hydroperiod model of vegetation distribution across differing fluvial surfaces (explained in the text). This figure shows a schematic representation of geomorphic features and associated vegetation types along Passage Creek, Virginia, USA (adapted from Hupp 1986).

occurs upon landform surfaces whose margins are periodically affected by pulses of river activity (e.g. Gill 1972; Fonda 1974; Nanson and Beach 1977; White 1979; Salo et al. 1986; Kalliola and Puhakka 1988). In rivers undergoing systematic channel migration, 'new' surfaces created through lateral accretion become established by 'opportunistic', primary colonising species (Fig 1a). These early successional communities reflect external, allogenic processes of flooding and aggradation at the point bar margin (Gill 1973). Orderly patterns of vegetation reflect phases of lateral channel shift and associated changes in the pattern of sediment deposition on the bar. Community structure changes through time, as organisms modify and gain control of the physical environment (Drury and Nisbet 1973). In this way, vegetation succession proceeds as a consequence of environmental alteration and competitive exclusion (White 1979).

The second model that accounts for the distribution of riparian zone vegetation cites external, environmental alterations as controls on the allogenic distribution of vegetation. In this hydrogeomorphic model, distinct vegetation assemblages are associated with geomorphic surfaces, the elevation and position of which determine the frequency, intensity and duration of flood inundation, sediment calibre, and the susceptibility of certain species to damage (Fig 1b; e.g. Bell 1974; Harris 1986; Hupp 1988; Hupp and Osterkamp 1985, 1996; Osterkamp and Hupp 1984; Teversham and Slaymaker 1976; Yanosky 1982).

This study tests the applicability of the successional and hydrogeomorphic models in explaining the vegetation distribution on a gravel point bar in the Wilson River, on the North Coast of New South Wales (NSW).

BACKGROUND CONTEXT: HUMAN DISTURBANCE TO RIPARIAN VEGETATION IN COASTAL NSW VALLEYS

The vegetation distribution along virtually all coastal plain rivers in NSW reflects landscape responses to the clearance of riparian zone and floodplain vegetation in the nineteenth century. Citing evidence from the lower Hunter River, along with the Manning and Nambucca catchments, Raine and Gardiner (1995) suggest that coastal rivers in NSW north of the Hunter contained stands of dense lowland sub-tropical rainforest at the time of European settlement. Channels were narrow, sinuous and relatively stable, and experienced negligible bedload transfer. Examples of the likely rainforest climax species include weeping myrtle (*Waterhousia floribunda*), watergum (*Tristaniopsis laurina*), flooded gum (*Eucalyptus grandis*), sand paper fig (*Ficus coronata*), cheese tree (*Glochidon ferdinandi*) and brush cherry (*Syzygium australe*). The rainforest also contained stands of the highly prized red cedar (*Toona australis*). Indeed, the cedar industry was one of the original mainstays of the economy in the early days of the colony (Gaddes 1990). By 1890, however, the cedar industry was all but finished in NSW, as easily accessible areas on floodplains had been logged. By this time, much of the lowland plain had been cleared of vegetation for agriculture.

Post-European clearance of riparian vegetation, altered fire regimes, depletion of the original seed base, grazing pressures and changes to river morphology have resulted in extensively modified patterns of riparian vegetation along rivers in coastal NSW. In instances where regrowth has been facilitated, it tends to be dominated by fast growing monocultures of opportunistic species, such as river oaks (*Casuarina cunninghamiana*), tea trees (e.g. *Leptospermum* sp.) and bottle brush (*Callistemon* sp.). These species can inhabit frequently flooded areas atop coarse gravel substrates. These are sites with high light levels, low nutrient availability, and low inherent fertility.

The site selected for this study records a history of opportunistic vegetation responses to channel expansion. Vegetation cover on the 'recent' point bar surface contrasts markedly with remnant stands of riparian vegetation at the channel margin.

REGIONAL SETTING FOR THIS STUDY

The Wilson River is a north easterly draining tributary of the Hastings River (Fig. 2). At Telegraph Point, the Wilson River drains a catchment area of 570 km^2. Headwaters are located in the Tinebank mountain ranges of the Northern Tablelands. The regional geology is dominated by mudstone, sandstone and conglomerate of the Carboniferous Boonanghi Beds.

In its upper 30 km, the Wilson River drops over 800 m to Upper Rollands Plains (see Fig. 2). At the base of the mountain range, the bedrock confined valley widens from <100 m to 500–700 m. The low sinuosity, gravel-bed channel is about 20 m wide. Downstream of Marlo Mericcan Creek confluence, the Wilson River is characterised by multiple channels with well-vegetated islands. Beyond this point, the valley widens to approximately 2 km. Various narrow (around 20 m), sinuous paleochannel threads are evident on the floodplain. The floodplain becomes increasingly swampy towards the tidal limit (around Telegraph Point).

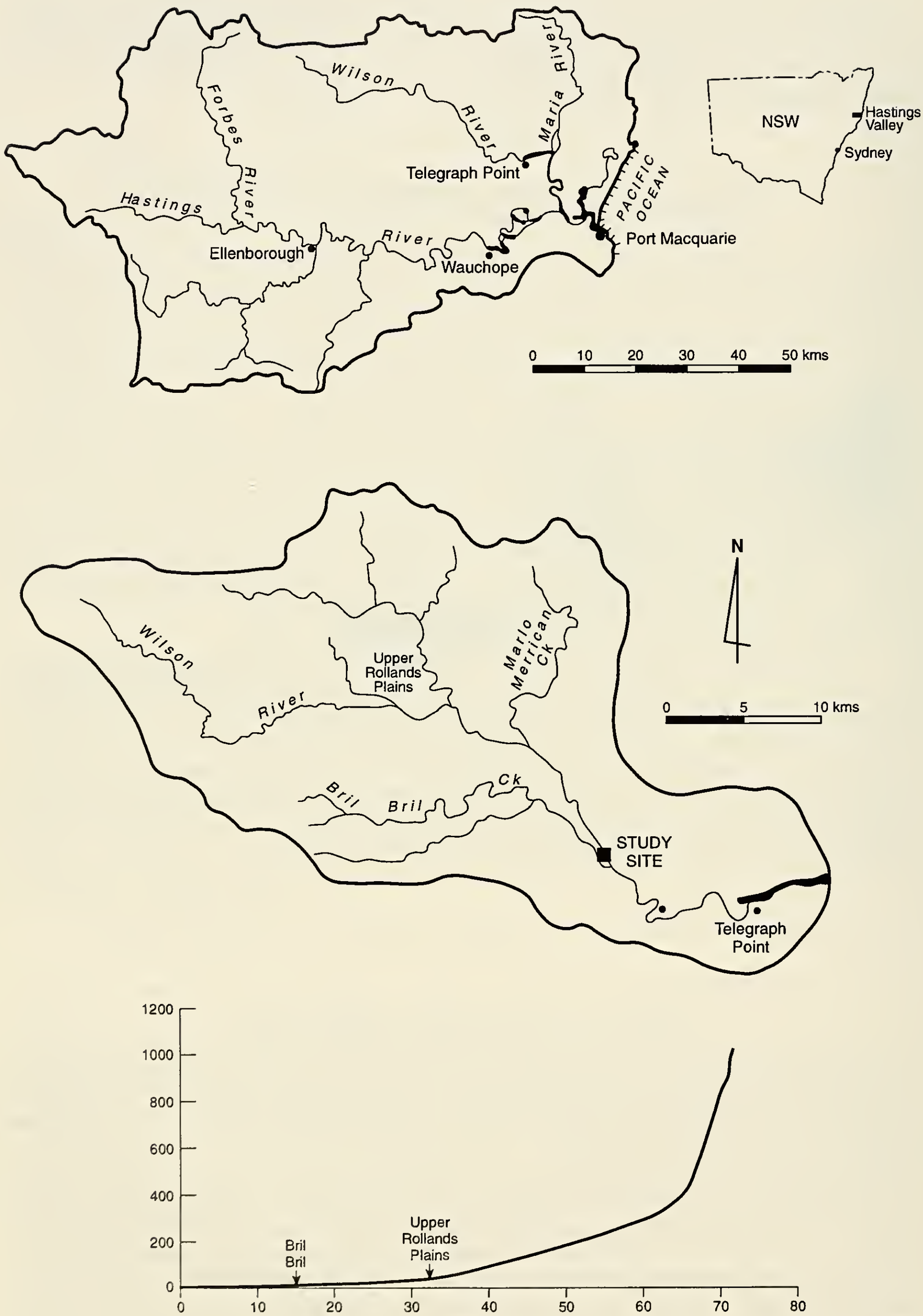

Figure 2. Location of the Wilson River and study site in the Hastings Valley.

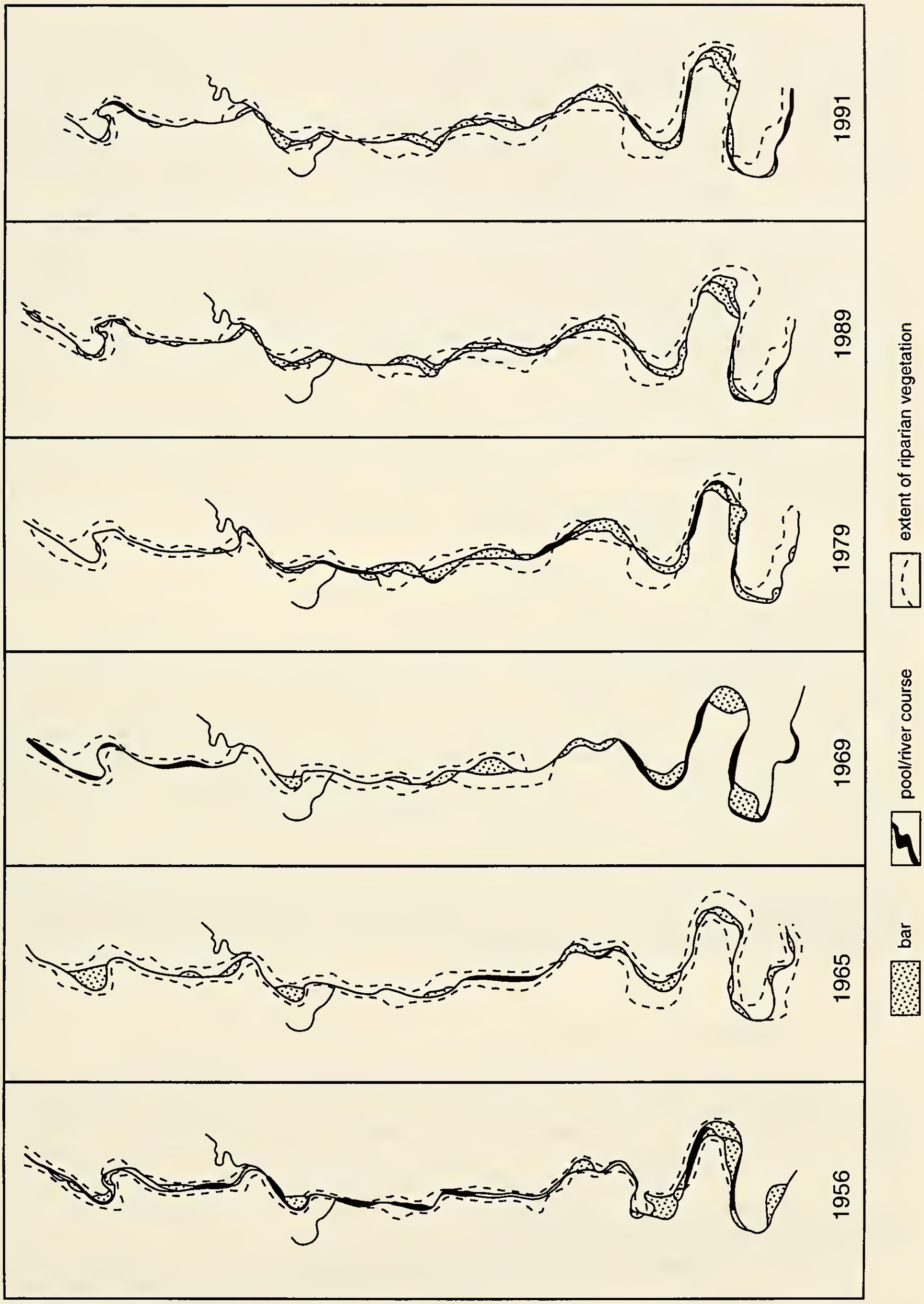

Figure 3. Air photograph interpretation of channel adjustments in the study reach (1942–1991)

Air photographs indicate that between 1942–1991 the lower course of the Wilson River has widened considerably and modified its planform (Fig. 3). At the study site, located on a large point bar approximately 600 m upstream of Bril Bril confluence, channel width increased from around 20 m in 1942 to almost 130 m in 1991. Field work in 1996 measured channel width at 170 m, indicating an increase of 750% since 1942. The channel has also incised by up to 2 m, exposing basal gravels on the concave bank. The studied point bar is approximately 150 m wide and 300 m long. The highest point on the bar surface is 2 m above the low flow channel.

Channel expansion along the Wilson River is a secondary response to bed degradation. Oversteepening of the channel bed has resulted in upstream migration of a nickpoint, and subsequent channel expansion. Widening has been especially pronounced at bends. Although the pattern of channel adjustments likely reflects an inherent, lagged response to vegetation clearance, changes in channel form have been accentuated by gravel extraction downstream of the study site. Given the enlarged channel size, low to moderate floods are more geomorphologically effective than in the past, as a greater proportion of flow is confined within the overwidened channel rather than being dispersed onto the floodplain surface. This combination of circumstances has accentuated bend expansion at the study site.

Mean annual rainfall in the area is around 1300 mm. Unfortunately, the discharge record for Wilson River is poor, with just 15 years of gauged data from the station at Avenal. These data indicate a bankfull discharge ($Q_{2.33}$) of 695 m^3s^{-1}.

METHODS

A base map of the study site was prepared at 1:12,000 scale, using an enlargement of the 1991 air photograph. Geomorphic units identified on the bar surface (*sensu* Brierley 1991, 1996) were used as the basis for a stratified field sampling technique. Nine tape and clinometer and two dumpy level transects were conducted at approximately 30 m intervals down-bar. Riparian vegetation composition, structural complexity, stem density and maturity of river oak (indicated by diameter at breast height, or DBH) were determined for each geomorphic unit. Gravel clast size was determined by b-axis measurement of 30 clasts at 1 m intervals along a line transect. For clasts whose b-axis was less than 8 mm, the nearest adjacent clast (> 8 mm) was measured. Clast shape was visually estimated as rounded, subrounded, subangular, or angular. The distribution of geomorphic units, clast size data, DBH results, and relative vegetation diversity (based on number of woody species) are summarised in Fig. 4.

VEGETATION DISTRIBUTION ON THE STUDIED POINT BAR

A diverse array of geomorphic units comprise the point bar complex (Figs 4 and 5). The morphology, position and bed material character of these units are summarised in Table 1. In subsequent sections the vegetation distribution is characterised at the bar head, mid-bar and bar tail.

Vegetation distribution at the bar head

The bar head comprises short, parallel ridges separated by chute channels (transects A to C on Fig. 5). A large fallen tree (DBH > 500 mm) has blocked off a bank-marginal flood channel, trapping a large amount of woody debris. The flood channel widens to 40 m in mid-bar (transect E on Fig. 5), but contracts to 5 m wide at the bar tail (transect I on Fig. 5). A large bench feature, up to 2 m high and 60 m wide, marks the left bank channel margin.

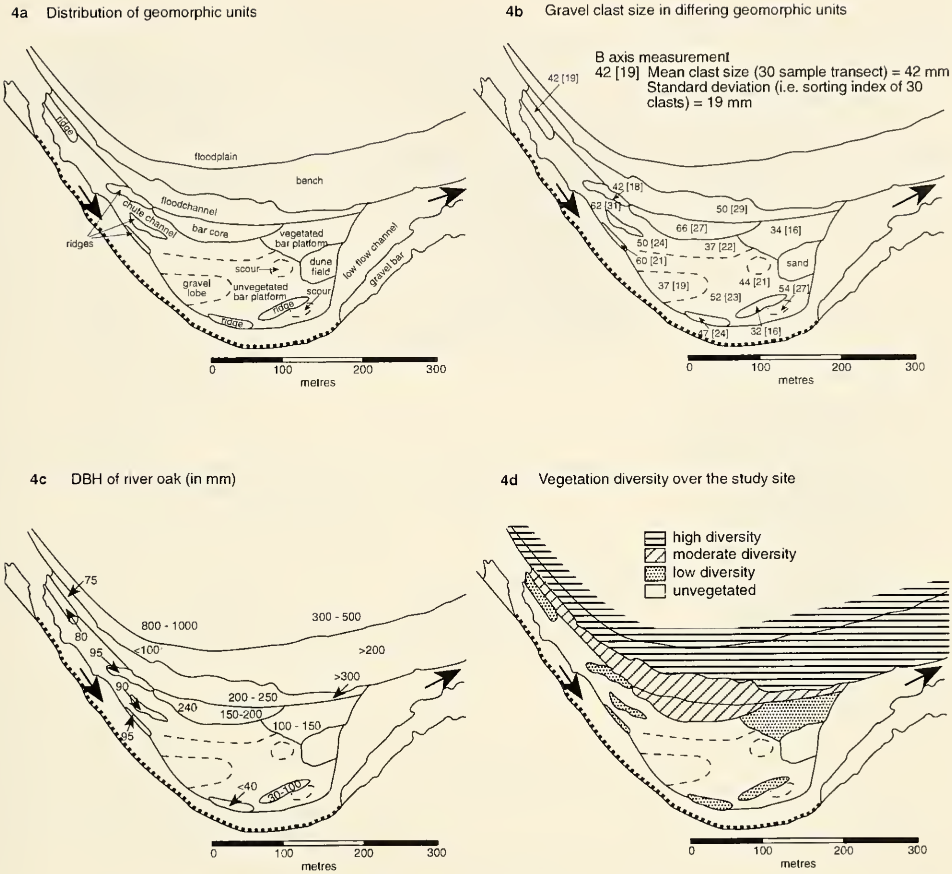

Figure 4. The point bar study site, Wilson River. (a) Distribution and location of geomorphic units over the bar surface; (b) clast size of differing geomorphic units over the bar surface (in mm); (c) diameter at breast height (DBH) of river oak on each geomorphic unit (in mm); (d) measure of vegetation diversity for differing geomorphic units over the bar surface, assessed as low diversity (2 or less woody species), moderate diversity (2–10 woody species), and high diversity (more than 10 woody species).

Chute channels and gravel ridges at the bar head support mainly young river oak, white sallow wattle (*Acacia floribunda*) and sporadic watergum in discontinuous bands parallel to the flood channel. Well sorted gravels have an average clast size between 40–60 mm (Fig. 4b). The DBH of river oaks is remarkably uniform across geomorphic units, ranging between 75–100 mm (Fig. 4c). There is no indication of a lateral trend in DBH of river oaks from the flood channel to the parallel ridges. Chute channels and gravel ridges at the bar head are distinctly lower than, and seemingly inset against, the left bank bench, where river oaks and distinctly older (DBH of 800–1000 mm).

Vegetation distribution in mid bar

Adjacent geomorphic units have widely varying character in the middle section of the bar, around the bar apex (transects D to H, Fig. 5). At the channel margin, gravels

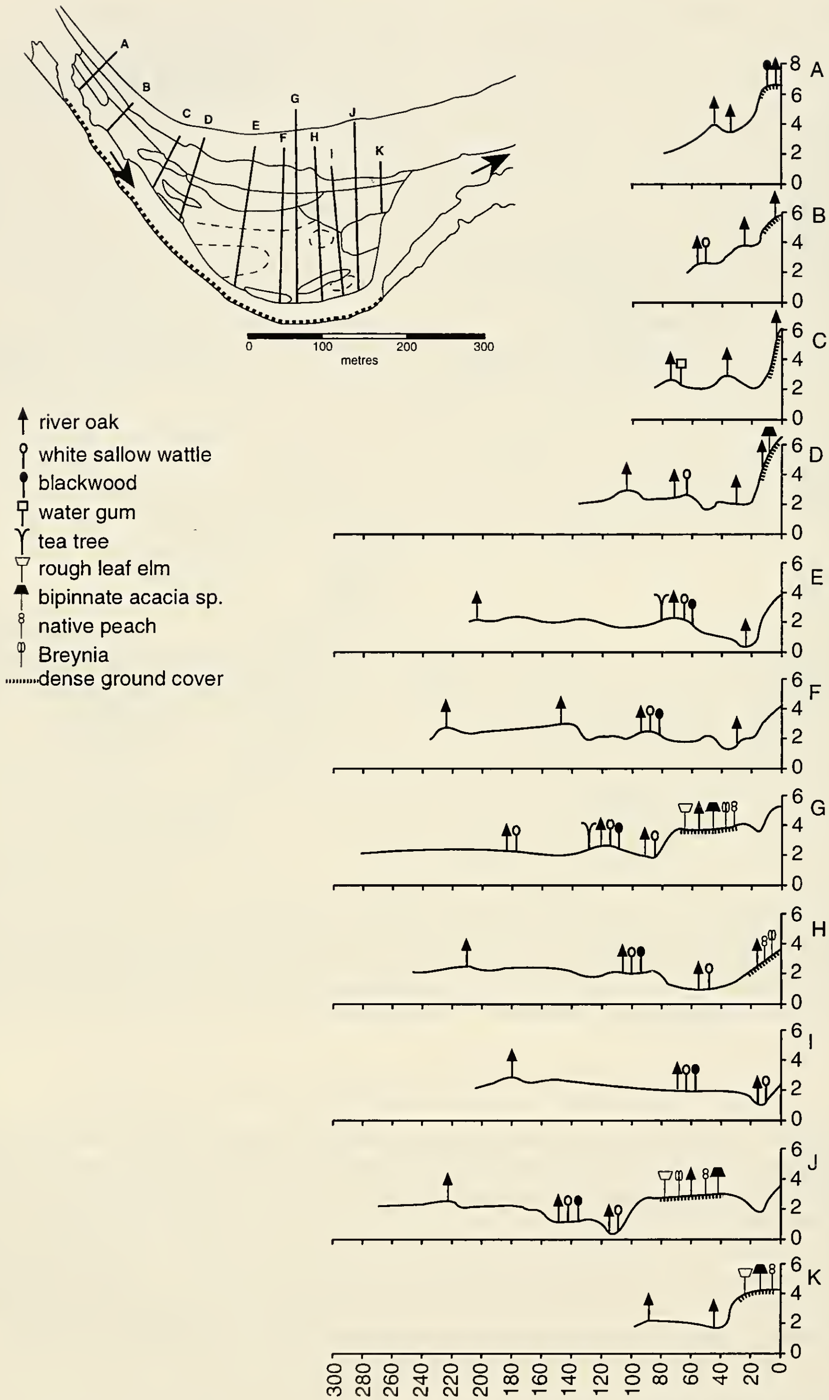

Figure 5. (a) Location of transects (A- K) across the point bar study site; (b) schematic representation of the composition and structure of vegetation assemblages on differing geomorphic units along each cross section (vegetation not to scale)

TABLE 1
Character of each geomorphic unit

Geomorphic unit	Morphology	Position on bar	Bed material character
Ridge	Linear, raised mound-like feature. Typically 5–8 m wide, < 1 m high, and < 50 m long.	Channel-margin features at the bar head or in mid-bar; may be found in a series of parallel forms, separated by chute channels.	Loose, uniform gravels with sand lenses. Average clast sizes range from 60 mm at the bar head to 30 mm at the bar tail.
Chute channel	Relatively straight, shallow channel that short-circuits the bend. Typically 10–30 m wide, < 0.5 m deep.	Primarily found at the bar head.	Loose gravels with discontinuous sand sheets. Average clast sizes range from 60 mm at the bar head to 40 mm in the gravel lobe at the bar apex.
Bar platform	Unvegetated surface, inclined slightly towards the channel. Arcuate shape, extending up to 50 m wide at the bend apex.	The dominant feature at the bend apex.	Average clast sizes range from 55 mm at the bar head to 40–50 mm at the bend apex.
Bar core	Irregularly shaped feature, with a relatively flat surface and eroded margins. Widens to > 50 m down-unit.	Separates the ridge, chute channels and bar platform from the flood channel.	Localised sand drapes (up to 50 cm thick) and scour features. Average clast size decreases down-unit, from 50 mm at the head to 35 mm at the tail.
Dune field	Irregularly shaped feature, characterised by unvegetated sand dunes. Extends up to 20 m long, 40 m wide.	Inset within the bar platform at the bar tail.	Sand.
Vegetated bar platform	Irregularly shaped feature, up to 40 m wide and 90 m long. Relatively flat surface.	Bar tail feature.	Dominated by sands up to 75 cm thick. Occasional gravels have b axis up to 35 mm.
Flood channel	Relatively straight and deep channel at the bar margin. Extends from < 10 m wide at the bar head to < 20 m wide down-bar. Depth locally increases up to 2 m deep. Irregularly scoured. Log jam at head.	Separates the complex pattern of geomorphic units on the bar surface from the bench at the left bank margin.	Prolific woody debris. Scour around trees. Generally sand-lined, but clasts in mid-bar have mean sizes of 50–65 mm.
Bench	Flat-topped feature, which widens to > 60 m down-bar. Surface drops from 4.5 m above the low flow channel at the bar head to 1 m above the low flow channel at the bar tail. Steep margin down to the flood channel and a graded slope to the floodplain.	Lines the left bank margin of the bar.	Sand and mud deposits.

have accumulated as ridges or as lobes within chute channels, locally elevating the bar margin above the older platform deposits (transects G and H on Fig. 5). Ridges lined with river oaks are not aligned parallel to the channel, as evidenced at the bar head. Gravel clasts are generally finer than at the bar head (typically 35–50 mm, Fig. 4b).

On the 'older' platform units at the core of the bar (DBH of river oaks 100–240 mm, Fig. 4c), mean clast sizes are generally coarser (between 50–60 mm), and clasts are rounder than elsewhere on the bar (up to 80% of clasts are subrounded, while the average figure for other geomorphic units is around 50%). Small gravel lobes and scour features indicate reworking of sediments at the bar core, with no linear pattern to the vegetation assemblage. The bar core supports a low open canopy of river oak and white sallow wattle, and a mid canopy of blackwood (*Acacia melanoxylon*), tea tree (*Leptospermum* sp.) and white sallow wattle. A moderate ground cover of native and exotic grasses and herbs has established. The vegetation association becomes more established towards the left bank, where mature river oaks (DBH up to 250 mm) form a tall upper canopy, with a mid-canopy of blackwood and white sallow wattle. The stem density of vegetation at the bar core is moderate to low, possibly reflecting natural thinning in response to competition for resources such as light.

In mid-bar transects the bar core is separated from the left-bank bench by a wide, sand-bedded flood channel, in which the mid to lower canopy and ground cover are poorly established. This reflects a greater degree of flood disturbance than at the bar core. Coarse woody debris caught up to 5 m high in mature river oaks (DBH around 120 mm) and white sallow wattle indicate that this is a high energy environment when floods are aligned down-valley rather than around-the-bend.

The bench surface at the left bank channel margin lies 2.5 m above the low flow channel, and has much older river oaks (DBH 300–500 mm) than adjacent geomorphic units, with wide floristic diversity and community structure. A small number of large river oaks dominate the emergent canopy. A significant proportion are dying or dead as a consequence of old age or fatal burial. Sands locally exceed depths of 100 cm on this surface. The upper and mid canopies are dominated by native species such as rough leaf elm (*Aphananthe phillipinensis*), bipinnate acacia, native peach (*Trema aspera*), breynia (*Breynia oblongifolia*), blackwood (*Acacia melanoxylon*), and a range of rainforest species. Exotic species such as lantana (*Lantana camara*), wild tobacco (*Solanum mauritianum*), stinging nettle (*Urtica incisa*) and camphor laurel (*Cinnamomum camphora*) have established a dense lower canopy and ground cover.

Vegetation distribution at the bar tail

The tail section of the bar is characterised by the most complex assemblage of geomorphic units over the bar surface (transects I to K on Fig. 5). Down-bar decline in bed material size is evident, as clast sizes at the bar tail are typically between 30–50 mm, with extensive sand deposition.

Moving away from the main channel, an unvegetated bar platform at the bar tail is transitional laterally to a narrow ridge colonised by young, partially buried river oaks (DBH 30–40 mm; occasionally up to 100 mm at the tail of the unit). Immediately behind the ridge is the downstream extension of the gravel lobe that infilled the former chute channel on mid-bar transects. As evidenced at the bar apex, this recent accumulation is higher than the adjacent bar core. The downstream end of the bar platform is highly dissected, with scour holes up to 3 m deep. Beyond these scour holes, a sand dune field has formed. Extensive sand deposition is also evident downstream of the bar core, where up to 75 cm of sand has been deposited around a dense monoculture of river oaks (DBH 100–150 mm). Significant aggradation and localised scour adjacent to the flood channel have been enhanced by dense stands of river oak, white sallow wattle and blackwood. Older river oaks (DBH > 200 mm) within the flood channel are indicative of lesser flood disturbance at the bar tail.

At the bar tail the left bank bench widens to 60 m. Surface relief varies by up to 2 m on this feature. Although this surface is less frequently inundated by low to moderate magnitude floods than adjacent units on the point bar, thick (> 1m) sand deposits indicate that flood disturbance is still a primary influence on vegetation composition, structure and survival. As observed in head and tail sections of the bar, vegetation composition and structure are more diverse on the bench than on other geomorphic units. Some river oaks have a DBH > 900 mm.

APPLICATION OF THE SUCCESSIONAL MODEL TO VEGETATION DISTRIBUTION ON THE WILSON RIVER POINT BAR

The vegetation distribution across the studied point bar has several indicators of vegetation succession. Moving away from the main channel:

1. Vegetation associations increase in complexity.
2. Species richness and structural complexity increase, reflecting a shift from disturbance tolerant species to less tolerant or intolerant species.
3. River oak, the dominant tree species across the point bar, increase in DBH (a surrogate for age).
4. Stem density decreases in more established, mature communities.

General successional trends are disrupted, however, by the irregular pattern of geomorphic units. Erosion in the flood and chute channels has defined boundaries between stands of vegetation, while deposition has created new surfaces suitable for initial colonisation. The irregularity of disturbances has created a mosaic of vegetation assemblages at different stages of colonisation and growth.

APPLICATION OF THE HYDROGEOMORPHIC MODEL TO VEGETATION DISTRIBUTION ON THE WILSON RIVER POINT BAR

The hydrogeomorphic model of vegetation distribution proposes that distinct vegetation communities are distributed upon geomorphic surfaces at different elevations above the low flow channel (Fig. 1b). On the studied point bar, the elevated channel-marginal bench contains a wider range of species, of greater age, than the remainder of the bar complex. The elevation of the bench presents a surface which is less prone to high frequency fluvial disturbances than the remainder of the bar surface. During flood stages, flow velocities on the bench are likely lower than over the bar surface, due to the lower flow depth and the dense vegetation cover. Substrate conditions on the bench are finer-grained than on the bar, and are therefore more able to retain nutrients and organic matter. Greater nutrient inputs from overlying vegetation enrich and develop the soil structure, enabling it to retain moisture more readily and consistently. Hence, these deposits have a higher fertility than the bar surface. For these reasons, the vegetation distribution on the bench comprises tall, floristically diverse species which are less flood tolerant than the vegetation cover on the bar itself.

However, elevation in itself cannot explain the pattern of vegetation over the bar. In general, the plants on the point bar are not grouped into discrete communities along an elevation continuum. Geomorphic units at differing elevations commonly have quite different substrate conditions and support different vegetation communities (e.g. the thicket of buried river oaks at the bar tail, and the stand of river oak, white sallow wattle and blackwood at the bar core). Of greater significance, however, is the recent nature of disturbance at this site, as many of the gravel accretionary surfaces that comprise the bar platform, including chute channels that are infilling with gravel lobes, remain unvegetated, yet these surfaces have a higher elevation than the diverse range of vegetation which comprises the bar core (see Fig. 5, transects G and H). At this site, where only 6 m separates the low flow channel and bankfull height, elevation of geomorphic units away from the main flow is not the dominant control on vegetation distribution.

FLOOD DISTURBANCE AS A CONTROL ON VEGETATION DISTRIBUTION

Channel expansion at the study site has presented a surface for opportunistic vegetation interaction with geomorphic processes. Most river oaks on the bar platform and

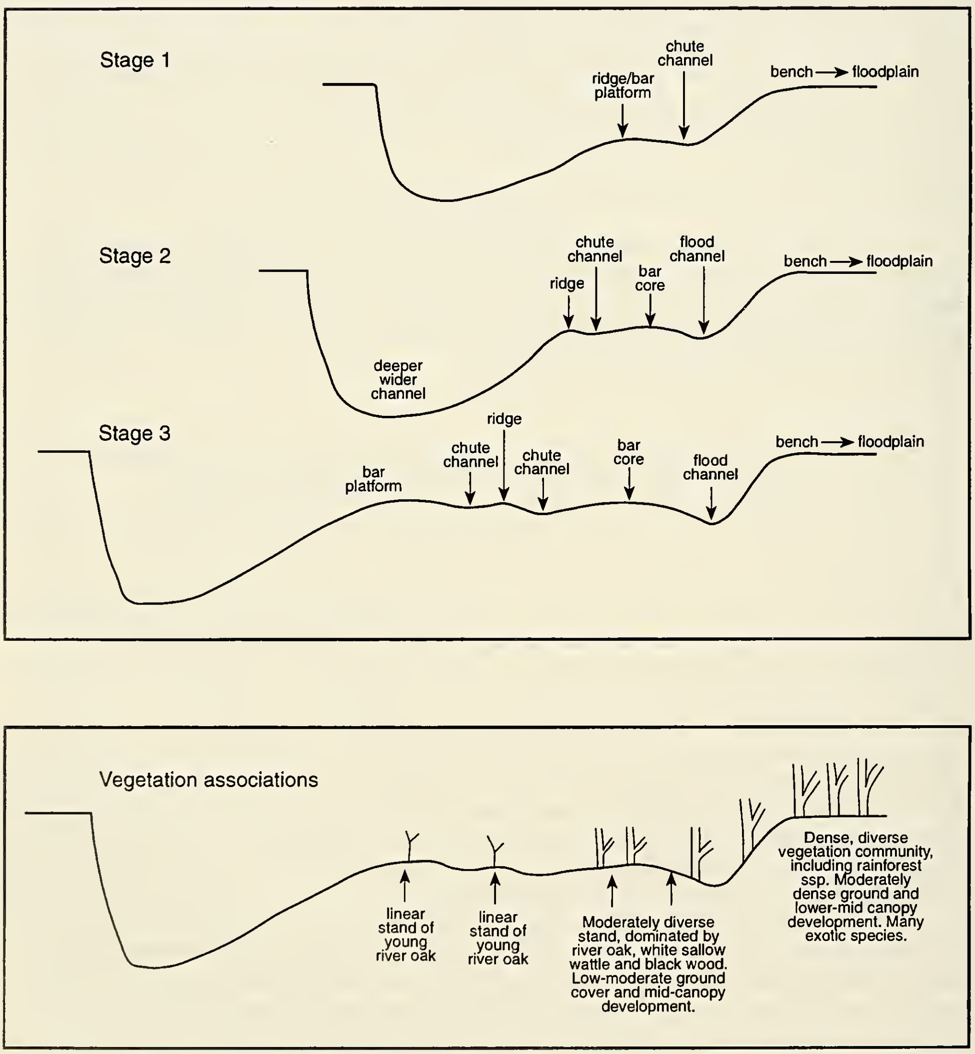

Figure 6. Evolutionary model of point bar formation associated with channel expansion at the study site (see text for explanation). Resulting vegetation patterns are shown schematically in the lower figure.

TABLE 2
Geomorphic units and their associated vegetation

Geomorphic unit	Species present	DBH of river oak	Vegetation structure (including stem density)
Ridge	River oak.	Up to 100 mm at the bar head, 30–40 mm at the bend apex and 30–100 mm at the bar tail.	Densely stemmed monoculture, typically just one-tree wide. Locally buried by gravels and sands up to 50 cm deep.
Chute channel	Unvegetated.		
Bar platform	Unvegetated, though some buried river oaks are evident at the head of the unit.		
Bar core	Low open canopy of river oak and white sallow wattle, with a mid canopy of blackwood, tea tree and white sallow wattle and a ground cover of native and exotic grasses and herbs.	Up to 240 mm.	Moderate density and diversity, with well-developed mid and lower canopies and grassed bar surface.
Dune field	Unvegetated.		
Vegetated bar platform	River oaks, with occasional blackwood and white sallow wattle.	100–150 mm.	Dense cover; virtually a monoculture of river oaks.
Flood channel	Characterised primarily by river oak, white sallow wattle and blackwood.	Less than 100 mm at the bar head, but up to 300 mm at the bar tail.	Irregularly spaced vegetation, with moderate diversity.
Bench	Upper and mid canopies are dominated by rough leaf elm, bipinnate acacia, rainforest species, native peach, breynia species and blackwood. River oaks dominate the emergent canopy. Exotic species such as lantana, wild tobacco, stinging nettle and camphor laurel have established a dense lower canopy and ground cover.	Up to 1000 mm	High diversity, with well-established upper and mid-canopies along with substantive ground cover.

associated ridges have DBH <100 mm, attesting to the recent nature of bend expansion. Channel-marginal river oaks were less than 5 years old at the time of field work, as they are not evident on the 1991 photograph.

The observed vegetation distribution reflects morphodynamic interaction between vegetation and geomorphic processes on the various geomorphic units that comprise the point bar complex (Figs 4 and 5; see Table 2). As geomorphic units are added to the point bar complex, or surfaces are modified to varying degrees during flood events of differing magnitude, the vegetation pattern changes. This, in turn, influences the geomorphic responses to subsequent flood events, resulting in a mosaic of geomorphic units with differing vegetation characteristics over the bar surface (Brooks 1994; McKenney et al. 1995). This *fluvial disturbance model* builds on the hydrogeomorphic model, applied to a lateral migration (successional) scenario.

Application of the fluvial disturbance model is accentuated in coastal valleys of NSW, where rivers have steep flood frequency curves, meaning that they experience large floods relatively frequently (McMahon et al. 1992). The geomorphic effectiveness of high magnitude floods is exaggerated by bedrock confinement of these valleys (e.g. Warner 1992; Ferguson and Brierley, in press). Responses to flood disturbance are further compounded at the study site, as channel expansion has effectively increased the frequency and duration of within-channel flows during high magnitude events.

Using DBH of river oaks as a surrogate for tree age, vegetation assemblages at different phases of regeneration and growth on differing geomorphic units provide an insight into the evolution of the studied point bar (Fig. 6). The bar core likely originated as a ridge and the adjacent chute channel subsequently became the contemporary flood channel (Stage 1 in Fig. 6). This scenario replicates ongoing processes at the bar head. Alternatively, the bar core may have evolved as a bar platform, which subsequently became separated from the bank by a flood channel.

As the channel degraded and the bend expanded, ridges developed at the channel margin associated with lateral accretion processes (Stage 2 in Fig. 6). Given their capacity to colonise and flourish under low nutrient, high light conditions, in gravelly substrates close to water, river oaks have been the primary coloniser of these ridges. River oak are able to establish and grow quickly (up to 3 m per year). When initially stabilising, there may be as many as 10–50 seedlings per square metre of alluvium, but they thin quickly through natural attrition. Deep, well spread roots resist up-rooting, while natural layering of adventitious roots enable them to survive rapid burial. Flexible, multiple stems of juvenile trees are able to bend with flow. Hence, stands of young river oak anchor the underlying gravels, enhancing deposition through increased flow resistance. Longitudinal strips of sediment accumulate in the wakes shed from initially established plants, creating a positive feedback situation of continued plant establishment in the accumulating sediment and continued sedimentation in response to the developing vegetation (Everitt 1968; Nanson and Beach 1977). Recurrence of this activity has produced a series of ridges at the bar head.

By enriching the substrate, along with its shading ability and capacity to trap sediment, river oak may facilitate the establishment of secondary colonising species (Raine and Gardiner 1995). This may well have occurred at the bar core. Species other than river oak establish between periods of inundation. Mineral substrates (particularly sands) develop structure, fabric and chemical reactivity from inputs of organic matter and nutrients from decomposing leaf litter. Edaphic developments are often reflected by the extent and composition of ground cover vegetation, such as grasses, herbaceous weeds and juvenile natives as seen on the bench at the convex bank margin.

Although the entire bar may be submerged at high flood stages, the significant degree of dissection of the bar surface, by flood and chute channels and by various scour features, indicates that extensive reworking of deposits has taken place at low-moderate flood stages. Associated with these events, there has also been extensive deposition of deposits over the bar surface, with selective deposition of sands and fine gravels at the bar tail. These factors have subsequently modified the potential for vegetative establishment and survival.

Given the enlarged channel at the study site, sub-bankfull floods have extensively modified the bar surface. For example, low-moderate magnitude events may promote infilling of chute channels and accentuate ridge development, whereas higher magnitude events may promote continued expansion of the point bar through concave bank erosion and lateral accretion. Even higher magnitude events may be aligned down-valley, activating fluvial reworking in the flood channel. Various phases of bar dissection and extension have produced a complex mosaic of geomorphic units across the bar surface, resulting in a patchy riparian vegetation community (Stage 3 in Fig. 6). Localised disturbances effectively sets succession back to the initial processes of colonisation and regeneration. This is referred to as gap phase succession (White 1979), whereby whole communities may become structurally affected as well as compositionally adapted to disturbance.

The vegetation distribution across the point bar is determined by the pattern of geomorphic units, which has produced a mosaic of plant communities of differing age and composition. These geomorphic units are subjected to flood disturbances of differing frequencies and severities. In several instances, distinct vegetation interactions can be discerned for differing geomorphic units:

1. Chute channels at the bar margin support young, sparse vegetation, reflecting recurrent phases of flood disturbance.
2. Channel marginal ridges support bands of young river oak which stabilise sediments and induce further deposition.
3. Older, more diverse stands of trees have established at the bar core.
4. Dense stands of young river oak at the bar tail facilitate sand dune deposition.
5. While the log jam at the bar head has induced some stability in the flood channel, promoting greater diversity of vegetation down-channel, flows are preferentially routed down the flood channel during high magnitude events, depositing sands in mid-bar transects and disrupting the vegetation distribution.
6. Due to their elevated position, older, less dense vegetation stands on the bench are less 'disturbed' than the lower point bar surface.

In this study, the geomorphic unit framework has been applied to a site which has experienced dramatic recent changes to channel geometry and planform. There are no obvious reasons, however, why the disturbance model could not be used to explain the pattern of riparian vegetation in other landscape settings (cf., Brooks 1994; McKenney et al. 1995). For example, the model is considered to be pertinent for virtually all coastal valleys in southeastern Australia.

As an postscript to this paper, the study site has subsequently been transformed by a Rivercare project. In an attempt to reduce the accelerated rate of concave bank erosion, a bed control structure has been built at the downstream end of the bend, and a bench has been constructed along the concave bank. Material for this bench was supplied from the point bar. The vegetation cover documented in this study has been removed, as the channel has been realigned along the left bank.

SUMMARY AND IMPLICATIONS

Models that directly relate riparian vegetation distribution to prevailing ecological, geomorphological or hydrological conditions *in isolation* overlook the dynamic, mutually interactive relationship between vegetation, channel morphology and hydrology. Differing vegetation assemblages on differing geomorphic units reflect variable responses of each geomorphic unit to floods of different magnitude and frequency. The pattern of geomorphic units underpins the vegetation distribution.

Prior to disturbance, it has been inferred that the riparian vegetation cover of coastal valleys in northern NSW reflected a mature phase, climax community, interspersed with patches of earlier successional plant communities (Raine and Gardiner 1995). In most valleys this situation is now reversed, with colonising species such as river oak now dominating areas that once supported diverse forest. Practical efforts at river rehabilitation in these disturbed riparian settings are increasingly focussing on revegetation strategies, framed within a 'soft-engineering' approach. Application of these approaches will be most successful if planting strategies 'work with' natural patterns of geomorphic and vegetation interaction. In general, this entails using fast growing primary colonising species at the outset, such as river oaks (*Casuarina* sp.), tea trees (e.g. *Leptospermum* sp.) and callistemon (*Callistemon* sp.). These multi-trunked species have root systems that extend below the water table, and grow in dense thickets. As such, they provide substantial resistance to flow and act as a means of gravel stabilisation. A number of sedges and rushes will perform well in conjunction with tree and shrubs on bars, benches and eroding banks. These species are effective at trapping wash load, thereby aiding the build up of cohesive materials on these surfaces. Examples include *Lomandra hystrix*, *Lomandra longifolia*, *Schoenoplectus mucronatus* and *Scirpus validus*. Full details of planting strategies are presented in Raine and Gardiner (1995).

Finally, for a fuller understanding of controls on vegetation distribution and composition on gravel point bars, a number of additional factors warrant further investigation, such as:

- Biotic processes involved in ecological succession, such as competition, inhibition and facilitation.
- Biotic responses to fluvial processes such as mechanical damage, inundation, accretion, scour and responses to variable water levels.
- Vegetation changes associated with soil development, moisture capacity, soil nutrient status, sediment size distribution and light availability.

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